Sonar-operator active noise reduction insert-earphone: Prototype preliminary test and evaluation.

by

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SUMMARY PAGE

Problem

With renewed interest in presenting relevant acoustic information to submarine sonar operators, especially the broadband-search sonar operators and sonar supervisor, headset selection presents a problem because of the degree of noise in the room and its spectral content.

Findings

Conventional noise-occluding (closed shell) headsets were designed for communication and are appropriately band-limited in frequency response to optimize speech intelligibility. Closed-shell earpieces confound accurate sound reproduction due to cavity resonance and interaction between frequency response and seal against the head. High-fidelity headsets, which extend frequency-response accuracy to well beyond the speech range, avoid using noise-occluding closed shell designs and as a result provide little noise attenuation at necessary frequencies. Active noise cancellation (ANC) headsets *have been* designed to solve both the noise reduction and bandwidth problem, but still require maintaining a good seal against the head. In addition, they tend to isolate the wearer from airborne voice communications occurring in the room. Advanced design insert *adaptive* Digital Noise Reduction (DNR) earphones with in-ear voice communications, have greatest potential for use by sonar operators if the frequency response can be further improved to match newer high fidelity ANC headsets currently in operational use.

At-sea measurements of the airborne noise at the location of the operator's head, reveals that its' low-frequency spectral content can severely interfere with operator detection performance. A high-fidelity ANC or DNR earphone is the least expensive solution to the noise interference problem and is also an immediate one. The best solution would be to reduce the noise at its source

The current research assesses a prototype DNR insert earphone device, with in-ear 2-way communications that, with minor modifications can meet those requirements. Noise attenuation measurements show the prototype capable of greater than 32dB reduction in airborne sound in 1/3-octave bands from 50Hz to 10kHz. This was achieved through microprocessor-controlled digital noise reduction, without the further application of onboard ANC. Frequency response, while adequate for speech, needs to be upgraded for use by sonar operators as was done on several ANC headsets. Given the capabilities of digital processing, this is a minor, though critical, issue.

More efficient command and control designs as found on Virginia Class further exacerbate the noise problem as common control areas increase the concentration of hardware ventilation fans and console operators. These earphones can also serve to selectively reduce speech interference from adjacent operators. With the proper response modifications, these earphones are also essential for Advanced Rapid COTS Insertion (ARCI) systems. Application of these earphones for surface naval operations is also strongly recommended.

Application

Design of sonar signal-processing equipment for optimal human auditory discrimination.

OPERATIONAL ABSTRACT

In trying to select an accurate method of presenting acoustic information to submarine console-operators, and in particular operators engaged in broadband-search, we are faced with a problem. The room is noisy. From accurate *in-situ* tests of the acoustic output of earphones of all types, it is clear that any noise-occluding headset or earphone, currently manufactured commercially, has a band-limited frequency response. Such band-limited earphones are *specifically* designed for communications. In the recent past, insert earphones were of limited bandwidth and therefore supplanted by sealed around-the-ear (circumaural) headsets. Because a *passive* noise-occluding headset requires a complete seal around the ear, headband pressures required for such a seal are extremely uncomfortable in extended wear. Once the headset has been specifically designed to work with a seal, the inability to consistently maintain that seal with each repeated placement over the ears, creates a major critical loss of low frequency signal output. Since conventional <u>passive</u> noise attenuation used in headsets is less effective at low frequencies, that critical loss of low frequency information in the received signal is even more deleterious to detection. With reduced low frequency output from the earphone, the airborne low-frequency components mask the relevant signal to be detected.

Commercial off the shelf (COTS) circumaural (around the ear) closed-shell headsets of excellent fidelity have been selected for BSY-2. But, high fidelity headsets have not been designed to attenuate noisy environments, therefore none attempt to tackle the formidable problem of maintaining a noise occluding seal against the head. Active noise cancellation (ANC) headsets circumvent the earcushon seal and headshell attenuation problem by acoustically monitoring the non-signal related noise inside the headshell and creating its inverse to actively cancel it. Also, because of their active electronics, ANC headsets can be equalized to reproduce accurately. ANC headsets solve the noise problem and dramatically improve detectability. Active noise cancellation (ANC) headsets *have been* designed to solve both the noise reduction and bandwidth problem, but still require maintaining a good seal against the head. In addition, they tend to isolate the wearer from airborne voice communications occurring in the room. Advanced design adaptive Digital Noise Reduction (DNR) *insert* earphones with in-ear voice-communications, have greatest potential for use by sonar operators if the frequency response can be further improved to match newer high fidelity ANC headsets currently in operational use.

Evaluation of COTS headset products confirmed our decision to press for development of high fidelity sensor operator earphones capable of removing low-frequency noise through active noise reduction. The current research assesses a prototype DNR insert earphone device, with in-ear 2-way communications that, with minor modifications can meet those requirements. Noise attenuation measurements show the prototype capable of greater than 32dB reduction in airborne sound in the 1/3-octave bands from 50Hz to 10kHz. This was achieved through microprocessor-controlled digital noise reduction, without needing further application of onboard ANC processes. Frequency response, while adequate for speech, needs to be upgraded for use by sonar operators as was done on several ANC headsets. Given the capabilities of digital processing, this is a minor, though critical, issue.

Because they can also function in very intense noise and under helmets and other over the ear protective devices, DNR insert earphones have potential for widespread military use.

ABSTRACT

In providing relevant acoustic information to the broadband-search and workload share operators as well as the sonar supervisor, earphone selection is at issue. The airborne listening environment is somewhat noisy, especially in lower listening frequencies. From accurate *in-situ* tests of the acoustic output of earphones of all types, it is clear that any noise-occluding earphones are band-limited. Characteristically, noise-occluding earphones are designed for use in communications where limited bandwidth is desirable. Noise-occluding headsets, which seal against the head to reduce noise, must maintain their seal or suffer a critical loss in low-frequency output. High fidelity headsets, on the other hand, are of open or vented design to avoid this seal problem, but as a result suffer from poor noise-attenuation. Active noise cancellation (ANC) headsets circumvent the headset-seal problem somewhat by electronically canceling unwanted noise and can also be internally equalized for accurate frequency response. ANC headsets are more expensive than conventional designs, but by effectively reducing low frequency interference, they achieve a dramatic improvement in at-sea detection performance. ANC headsets *have been* designed to solve both the noise reduction and bandwidth problem, but still require maintaining a good seal against the head. In addition, they can isolate the wearer from direct communications with others in the room. Advanced design adaptive Digital Noise Reduction (DNR) *insert* earphones with in-ear voice-communications, have greatest potential for use by sonar operators if the frequency response can be further improved to match newer high fidelity ANC headsets currently in operational use.

Evaluation of COTS headset products confirmed our decision to press for development of high fidelity sensor operator earphones capable of removing low-frequency noise through active signal processing. The current research assesses a prototype DNR insert earphone device, with in-ear 2-way communications that, with minor modifications can meet those requirements. Noise attenuation measurements show the prototype capable of greater than 32dB reduction in airborne sound in the 1/3-octave bands from 50Hz to 10kHz. This was achieved through microprocessor-controlled digital noise reduction, without needing further application of onboard ANC processes. Frequency response, while adequate for speech, needs to be upgraded for use by sonar operators as was done on several ANC headsets. Given the capabilities of digital processing, this is a minor, though critical, issue.

This study reports evaluation of a prototype high fidelity DNR *insert* earphone with onboard voice communications being developed to our specification for use in critical listening by sonar operators in a noisy environment. Because it can also function in very intense noise and under helmets and other over the ear protective devices, it has potential for widespread military application.

ADMINISTRATIVE INFORMATION

This investigation was conducted under work unit #90852.001-50213 entitled "Sonarmen Earcup Technology". The views expressed in this report are those of the author(s) and do not reflect the official policy or position of the Department of the Navy, Department of Defense, or the U.S. Government. This report was approved for publication on 18 February 2003, and designated as Naval Submarine Medical Research Laboratory Report #1225.

INTRODUCTION

In modern accurate sound reproduction the weakest link is not the capture of acoustic energy and transfer to electrical energy but rather its regeneration back to an acoustic signal. That reproduction becomes even more difficult in a noisy confined space. The simplest way to avoid the confounding of room acoustics with sound reproduction is through the use of earphone headsets.

For our particular application in accurately presenting acoustic information, especially sonar target information, in the confined and hardware-cluttered space of a military vessel, earphones are ideal. Although the task of accurate sound reproduction now becomes simpler, it is still a formidable one.

The first major obstacle now becomes the accurate evaluation of earphone frequency response so that we can predict the sound pressure level for a given voltage at any specified frequency. Given the added requirement of listening in a noisy environment, an occluding noise attenuating earphone is necessary. Either an around-the-ear (circumaural) headshell or insert earphone is a possible solution. Given the limited broadband fidelity available from these types of in-ear devices in the recent past, the best choice had been through use of sealed circumaural headphones. Shaw and Thiessen (1962), Shaw (1965), and others found that standard headphone coupler measurements did not represent sound pressure measurements taken inside headphone headshells using calibrated probe-tube microphones. Based on these findings, a report by the United States of America Standards Institute Writing Group S3-1-W-37 on the coupler calibration of earphones (Benson et al 1967) concluded it could not justifiably write a *standard* for the coupler calibration of circumaural headphones.

Russotti et al (1988) devised a technique, which accurately measures earphone response when acoustically loaded by an ear-simulator and referenced to the diffuse free-field. The ideal earphone reproduces the information without imparting any alteration in the original signal. Using this technique, measurements of both military and commercial off-the-shelf (COTS) high-fidelity headsets were taken and recommendations were made for headsets for application in passive aural sonar. In experience gained over 15 years of testing earphones using this measurement technique, open-air circumaural earphones and closed earphones having a controlled pressure-leak were found to produce the most consistent and most accurate frequency response. Earphones designed to completely seal around the listener's ear produce large variations in their low frequency response due to a less than perfect seal. Differences in head size, gaps between the mandible and neck, and presence of hair and eyeglass temple-pieces all can contribute to a less than perfect seal. As a consequence, passive noise-occluding-earphone headsets, which require a good seal to occlude the ear canal for noise attenuation, are not a desirable design for accurate sound reproduction. Tests of military and commercial headsets have found that noise-occluding earphones are also characteristically band-limited (Russotti, 1995). Such headsets were originally designed for communications and are cost effectively band-limited to the speech range for that application. Despite the superior response accuracy of commercially available high-fidelity headsets, in selecting headsets for use in the noisy environment on all but the newest quieter sonar suites such as BSY-2 (Commanding Officer, Naval Submarine Medical Research Laboratory 1990) such high fidelity headsets could not be recommended. Because of their poor noise attenuation characteristics, ambient noise levels masked the signal in the headset. Instead, custom modified Active Noise Cancellation (ANC) headsets were designed to produce more accurate frequency response. These frequency-enhanced versions were recommended because of their demonstrated ability, during at-sea tests, to enhance detectability of contacts (Commanding Officer, Naval Submarine Medical Research Laboratory, 1993).

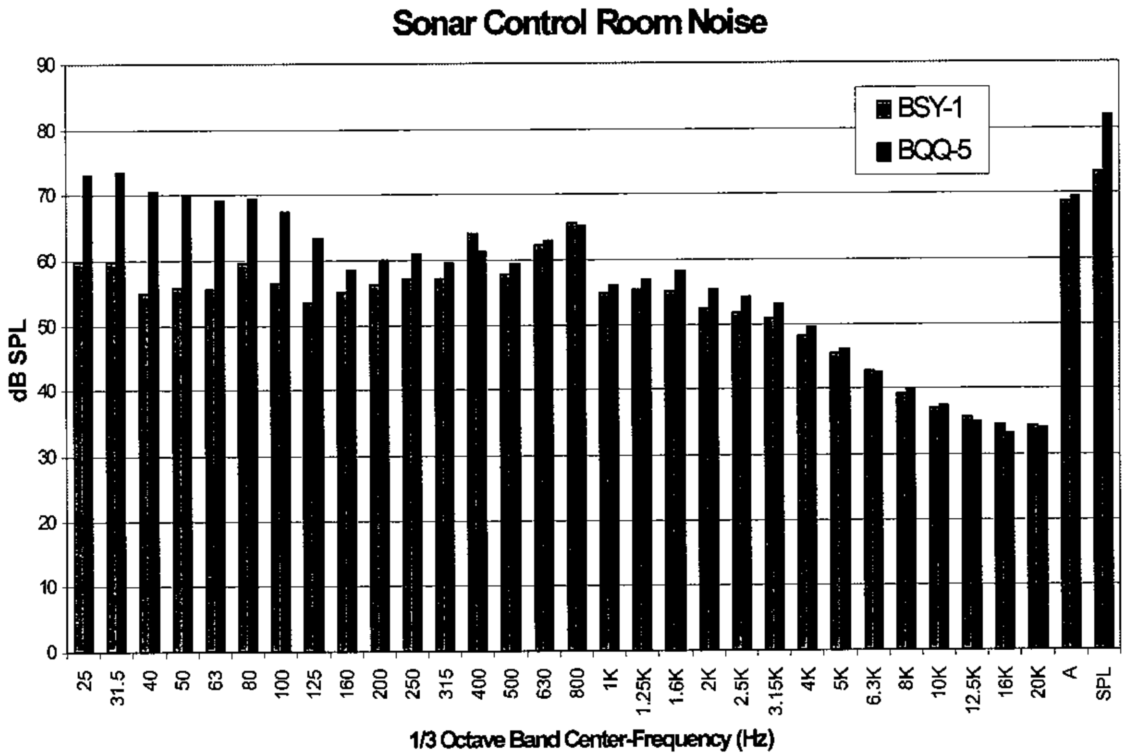

Figure 1. Spectral representation of sonar compartment on BQQ-5 and BSY-1 systems

Noise measurements (Russotti, 1998; Heller et al, 2000) clearly document the spectral content and intensity of airborne-noise in BQQ-5 *and* BSY-1 sonar spaces. The measurement system, used in place of a traditional sound level meter, complies with ANSI S1.4-1983 and S1.6-1984. Figure 1 presents a graphic comparison of differences between BQQ-5 and BSY-1 sonar control room noise. Root mean square (RMS) averages of the energy measured in 1/3-octave bands are depicted. Time-averaged sample-duration was approximately 30 seconds. All measurements are depicted re 20 μ Pascal. Comparisons are shown in 1/3-octave bands from 25 Hz to 20 kHz. At far right, dBA and overall dB SPL are represented as A and SPL respectively. The overall RMS, A-weighted, and 1/3-octave band data were averaged across data gathered at the operator's Command/Display Consoles (CDCs) and at the position of the sonar supervisor.

Although within safe noise levels for hearing conservation, BSY-1 and BQQ-5 systems have excessive noise in sonar operator work-areas where critical listening is required. There is significant low-frequency energy below 1 kHz. As seen in Figure 1, bands with center frequencies of 400, 630 and 800 Hz are above 60 dB SPL on both systems. For BQQ-5 there is especially unacceptable low-frequency noise in the region below 160 Hz. At those frequencies, and in fact at all frequencies below 500 Hz, attenuation *available* from conventional *passive* noise reducing headsets is greatly reduced and inadequate.

The presence of this high level of airborne low-frequency noise in the listener's ear, when wearing a *passive* noise reducing headset, means that there is inadequate dynamic range above the noise floor at normal listening levels. Since the overall level of the sea noise signal in the headset must be kept at a reasonably comfortable and safe level, these constraints result in airborne noise masking the low-frequency component of the target signal to be detected within the sea noise. This explains why previous reports (Russotti, 1993; Benedetto et al, 1995; Russotti, 1995) found improved sonar operator performance with ANC headsets. Should the target of interest have most of its radiated energy in these lower frequencies, the decrement in performance caused by the interference of this low-frequency airborne noise becomes even more detrimental.

ANC communications headsets use real-time techniques to remove unwanted acoustic signals that have passed through the headshell. A microphone inside each headshell provides a monitor signal, which is electrically compared against the headphone input-signal. The difference is inverted and added to the electrical input to cancel the unwanted energy inside the headshell. Inherent in such unique design is the potential to correct for diminished output due to a poor seal and the capability of enhanced frequency response through active equalization. Interactive work between Bose Corporation and NSMRL produced a *modified* version of their ANC commercial aviation headset with enhanced frequency response for use in passive sonar. These headsets (Bose Series I commercial aviation headset-[*nsmrl prototype*]) have been tested at-sea with highly favorable results and commensurate acceptance by the sonar community (Russotti 1993, Russotti 1995, Benedetto, et. al. 1995, Commanding Officer USS San Juan 1993, Commanding Officer USS Albuquerque 1995). Subsequently the Bose Series II Aviation headset in standard form exhibited even more accurate response than our custom Series I model. These models have been supplanted by the Series X Aviation headset a superior design more comfortable more durable headset, which was initially of lesser broadband fidelity. Subsequent work with Bose resulted in electronic modifications to enhance broadband fidelity of the commercially available Series X model (Russotti and Schwaller 2001). These modifications are now standard on the commercial Series X model (personal communication Bose Corp. 2002).

Recent advances in miniaturized transducers and microchip technology have allowed the development of a prototype noise-occluding earplug earphone, which may provide a far more useful interface to the sonar operator's auditory system. In addition to sound reproduction, this ultra-light in-ear device, not only reduces the environmental noise that enters the ear canal, it selectively reshapes it. The device digitally processes the outside airborne energy collected by the external ear and continually modifies it to selectively enhance the received signal. To execute this, the device uses three transducers. An external microphone receives the signal at the ear canal entrance. An internal "speaker" generates sound in the occluded ear canal, while a second microphone monitors all of the sounds in the ear canal. Using these three transducers a microprocessor digitizes and manipulates the signal generated in the listener's ear. Algorithms adjust bandwidth and attenuate sudden peaks in the regenerated signal relayed to the ear canal. Using microprocessor controlled Digital Noise Reduction (DNR) all external sounds are continually adjusted to both protect the ear and to selectively process-out interfering "noise" based upon its spectral content. Where required, the system applies ANC. But, to conserve power, only as necessary.

As an added feature, the occluded ear canal provides an optimal locus for capturing the wearer's vocalizations. The internal microphone accurately picks up the speech of the wearer with little interfering background noise.

The present research task was undertaken to implement the use of lightweight DNR/ANC insert earphones of appropriate fidelity to effectively reduce low-frequency interfering noise, which cannot be reduced using conventional passive noise reduction headsets. Given the concentration of console operators and hardware, noise reduction was essential not just for critical sonar listening but to ensure that speech intelligibility be maintained at maximum levels.

Figure 2. Headphone under test on KEMAR manikin

HEADSET RESPONSE

METHOD

The measurement technique we devised in 1985 and proposed for use in earphone calibration in 1986 uses a laboratory type Zwislocki ear **simulator** which includes multiple cavities to model the acoustic load that an average human wearer would place on the earphone element. Impedance measurements of human ears, by Zwizlocki (1957), Ithell (1963a, 1963b) and Delaney (1964), lead to development of several ear simulators. Zwislocki's (1970, 1971) easily replicated device successfully simulated the complex impedances found in average human ears. In standard form, this coupler uses a machined surface and fifth resonant cavity to simulate the external ear (or pinna). In developing a test and evaluation tool for hearing aid performance, Burkhard and Sachs (1975) incorporated the eardrum simulator portion of the Zwislocki coupler into the anthropometrically average manikin KEMAR. They accurately substituted flexible pinnae and metal ear canals for the corresponding portions of the Zwislocki coupler. Acoustic measurements on this version of the KEMAR manikin are in close agreement with similar measurements on human subjects (Burkhard, 1975), and the KEMAR manikin now conforms to ANSI (1985) standards intended for airborne sound measurement.

Figure 2 shows the KEMAR manikin as used in our application. The measurement procedure is outlined in detail in Russotti et al., 1988. The Zwislocki coupler, modified in the KEMAR manikin, has decided advantages for earphone evaluation over a hard-surfaced machined plate, in that any *wearable* earphone element can be tested. Earphone and headset design should be free from coupler imposed constraints. For a real ear, and also for the simulator, the airborne acoustic signal that arrives at the eardrum has had its frequency response modified by the external ear structure, by resonance created by the pinna, and by the complex loading of the ear canal and eardrum with its ossicular chain. For practical use a conversion function is necessary to relate the received signal at the eardrum back to the airborne sound environment. This converted response should correctly reference the signal measured in the coupler back to the external sound field. If the original airborne signal had equal sound pressure across frequency then the properly converted transformation of the signal measured at the "eardrum" should produce this same flat response. If instead of airborne presentation a headset or insert earphone is used, then it too should re-create this flat response. By referencing the signal back to the airborne sound field we can evaluate how well the earphone recreates the original airborne sound the ear would have heard. In practical terms if a constant voltage signal is supplied to the earphone over the frequency range appropriate for the ear simulator, the transform-corrected response measured by the ear simulator should ideally be a straight line.

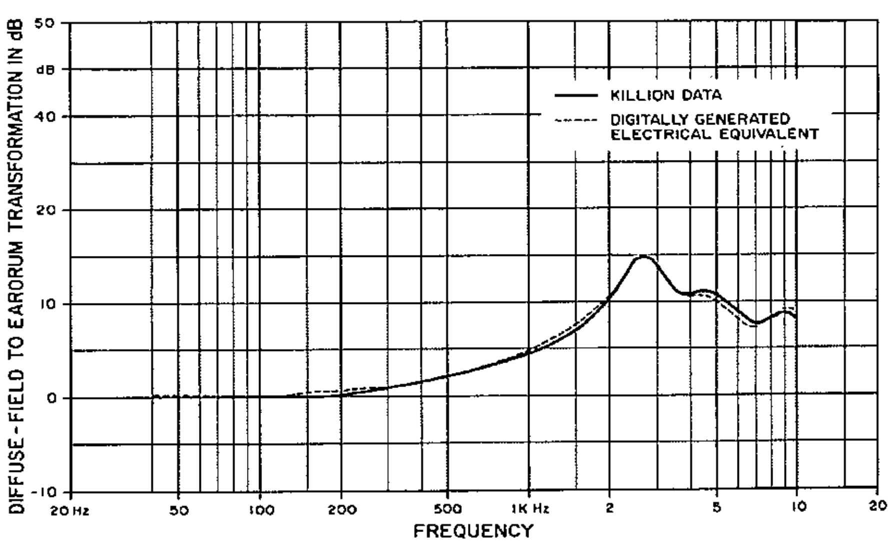

Figure 3. Conversion function necessary for diffuse-field transformation.

The required conversion function shown in Figure 3 references the earphone element response back to the diffuse field. This transformation is the response of the human ear, or in this case the manikin-mounted ear simulator, without regard to any one direction. Diffuse field measurement removes directionality created by the head and pinna from the transformation. Should directionality need to be coded into the presentation then head-related transform functions (HRTFs) can be imposed onto the electrical signal presented to each ear. Earmuff shape, size, seal, headband effectiveness and placement of headset on the head and against the ear are all major contributors to the variability one finds in earphone response measurements. Our technique samples these variables taking 5 measurements each, of 4 earphone elements. The headphone is removed and repositioned for each of the 20 measurements. All of the x y plots of sound pressure as a function of frequency are stored using an A/D converter. They are averaged and the diffuse-field conversion function applied

As a comparison, the upper left curve in Figure 4 shows a prototype supra-aural (on the ear) earphone tailored to have flat response on a standard 6cc ANSI volumetric coupler. Below it is the averaged response of the same earphone element measured on the ear simulator. This lower curve is the diffuse-field corrected response of the earphone measured with appropriate acoustic impedance coupled to the earphone output. Note the huge difference in measured response with proper acoustic load placed on the earphone.

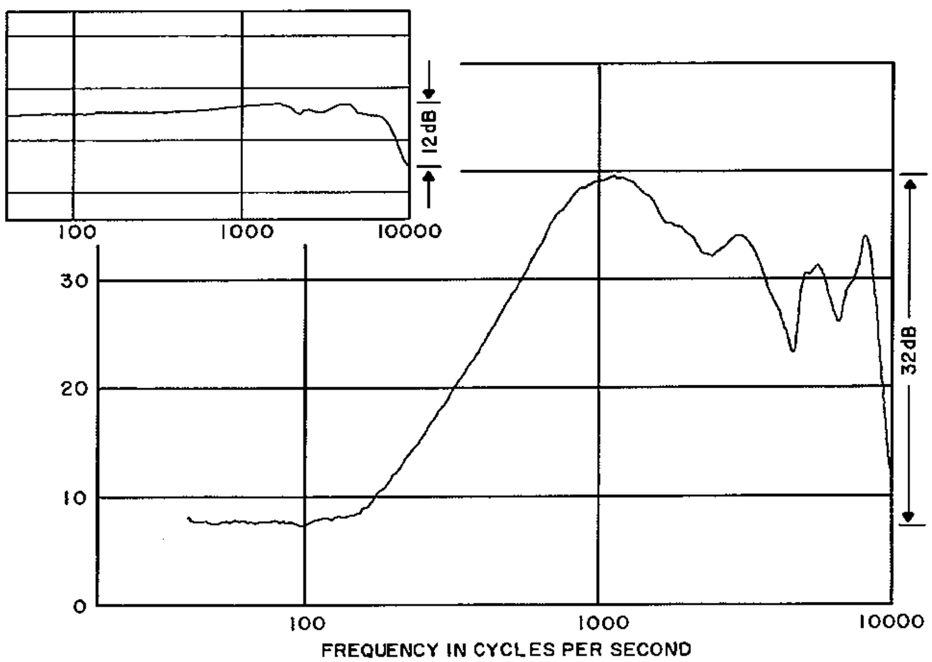

Figure 4. Earphone response on ANSI 6cc coupler and as measured loaded by an ear simulator.

Previous distortion measurements using ear simulators have shown that headsets of appropriate frequency response accuracy have extremely low distortion that is close to the limits of the necessary measurement hardware (Russotti et al 1985). In that study, at 95 dB SPL nine of the 11 top models, in response accuracy, had distortion levels of less than 0.1%. Distortion components limit an earphone's response accuracy as they waste energy when being generated by the transducer (earphone).

As a criterion for headset accuracy then, smallest variation in acoustic output in the 40 Hz to 10 kHz frequency range was the design goal, given the unknown and potentially changing spectral composition of the signal to be detected. Accurate reproduction of all energy in the 40 Hz to 10 kHz bandwidth would allow accurate representation of the signal to the ear.

As an outcome of this earphone design goal, combined with a need for active noise reduction a frequency-enhanced Series X prototype was redesigned from the COTS model and two samples were tested at NSMRL. Averaged results of diffuse-field response testing are presented in Figure 5.

As seen in the figure, the total variation of the Bose/NSMRL prototype is 13 dB from 40 Hz to 10 kHz, and 9.5 dB from 100 Hz to 10 kHz. This is a vast improvement from the COTS model. This is the headset currently in use on the newer upgraded sonar systems as well as the Virginia class sonar system prototypes under development. A lightweight noise reducing insert earphone that matches or exceeds these response characteristics would be a more desirable solution.

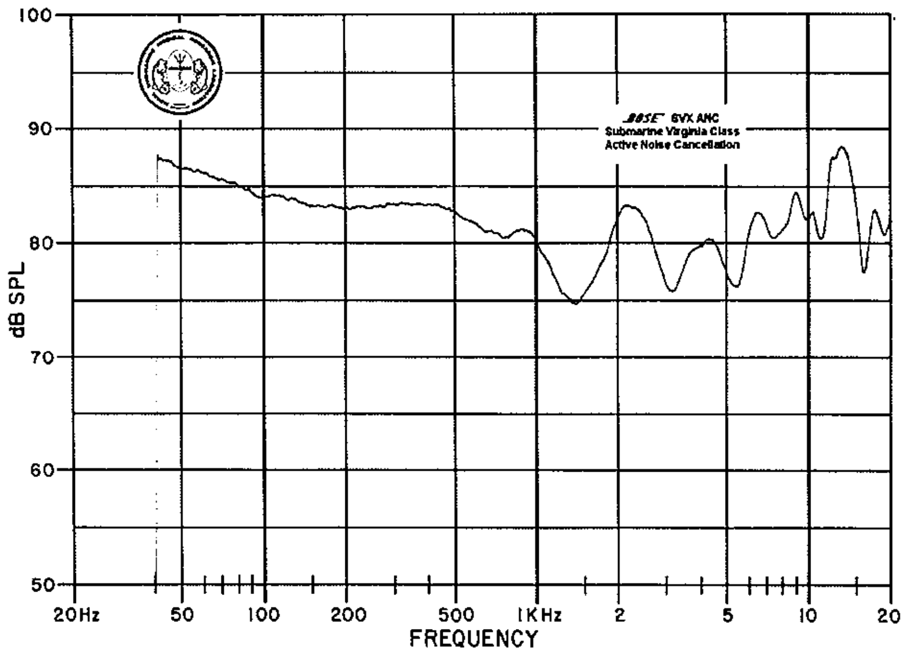

Figure 5. Averaged Diffuse-field response of Bose Series X *Submarine Virginia* [SVX] prototype.

FREQUENCY RESPONSE RESULTS

Figure 6 represents the diffuse field response characteristics of the Phase I Gentex prototype DNR insert earphone. Responses were averaged from a pair of earphones, with 5 measurements taken from the right and 5 from the left earphone. The figure illustrates the exceptional accuracy (5dB total variation) from 40Hz to 1.3kHz. However, because of rapidly diminishing output above that point, total variation was 33dB over the 40Hz to 10kHz range for this early prototype.

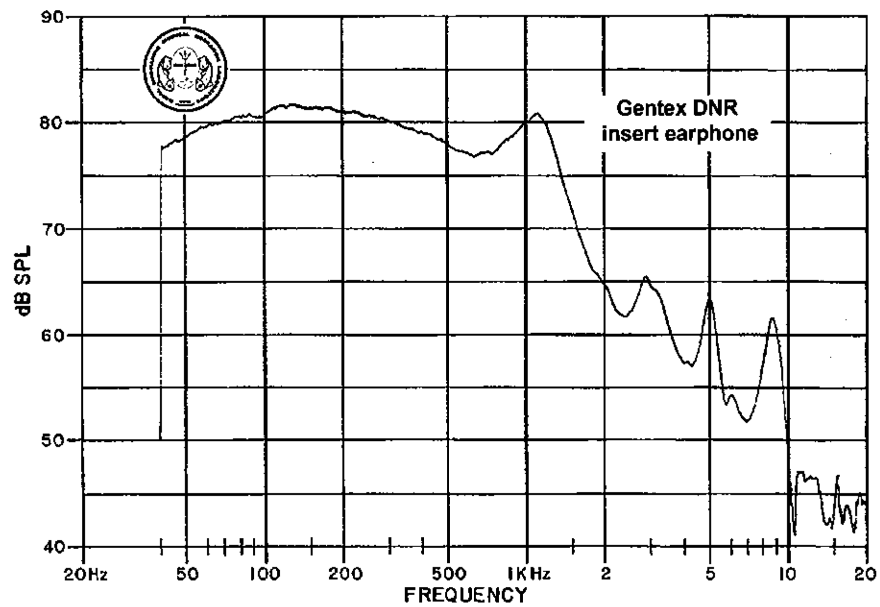

Figure 6. Averaged diffuse-field response of Gentex DNR insert earphone.

HEADSET NOISE ATTENUATION

METHOD

Because anticipated noise levels in sonar spaces would be well below damage risk criteria, standards for hearing protectors (ANSI S12.6-1997) were not required. In addition ANSI measurements do not assess the attenuation characteristics below 125Hz. Objective 1/3 octave-band measurements of the intrinsic ability of the noise-attenuating earplugs to reduce noise were conducted using a specially modified KEMAR manikin. Pliant bags of lead shot placed within the manikin were used to block sound transmission to the calibrated microphone "eardrum" from pathways other than the ear canals. Electroacoustic measurements of noise attenuation were made using various methods to occlude the ear canal. Differences in the received signal measured between open and occluded ear canal were derived in 1/3 octave-bands for a free-field pink noise signal.

A high-intensity sound system was instrumented to operate within a 30 x 16.5 x 11 foot high cement-block-walled reverberant room. The system consisted of four speaker arrays, each containing two 18 inch drivers, a 15 inch driver, and one 4 inch diameter titanium horn-driver. Each transducer was independently powered, by a configuration of Crown amplifiers capable of producing 1,310 watts RMS in each of 4 channels with Total Harmonic Distortion (THD) at less than .02% at rated power. Each channel of the system was fed by a separate channel of a Digidesign Pro Tools III digital hard disk recorder/editor. Four analog output channels of a Digidesign 888 interface were distributed to the amplifiers of each array through a pair of Rane AC-23 active crossovers. Just ahead of the AC-23 inputs, each of the channels was digitally controlled by a separate Wilsonics model PATT attenuator. Using the Digidesign system, each of four pink noise signals were fed through the separate speaker arrays to produce a homogeneous sound field of 94 dB SPL re 20 micro (μ) Pascal. Sound level measurements were taken without the manikin present at the location that would be occupied by the manikin head.

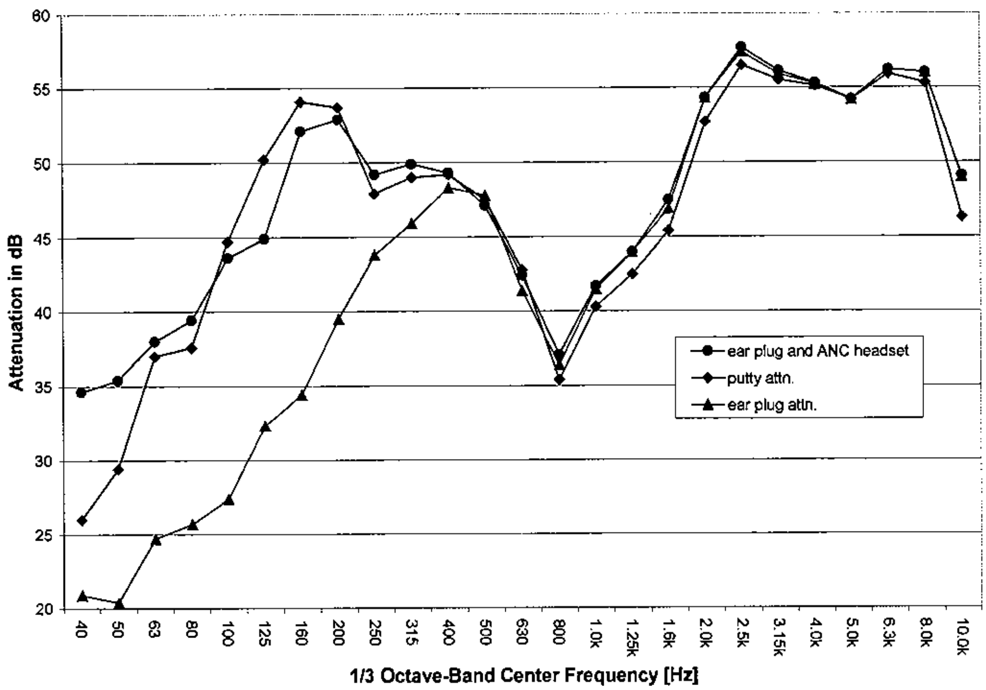

Figure 7. Occluded-ear attenuation characteristics of Kemar manikin using various methods.

Ear simulator output was spectrally analyzed using a Data Physics ACE signal analyzer. Headset noise attenuation was calculated as the relative difference between *open* ear and ear *occluded* by the noise occluding device under test. Root mean square (RMS) averages of the energy measured in 1/3-octave bands were calculated. These represent the relative attenuation afforded by the device under test. Baseline test results, shown in Figure 7, confirmed the ability of our modified manikin to attenuate such transmission at 35 dB or greater from 50 Hz to 10k Hz when the ear canal pathways were blocked. These data allow us to assess the maximum attenuation that can be measured on the manikin across frequency. The earplug used was an EAR *Classic* foam plug. The putty used to occlude the ear canal entrance was non-hardening (99% solid) electrical duct seal compound [GB Electrical]. The ANC headset used was the Bose Series X. As seen in the figure, with the exception of a 3 dB dip at 800 Hz, attenuation was 40 dB or better 100 Hz to 10k Hz. The combination of ANC headset over the EAR plug provided the best occlusion and estimate of maximum manikin attenuation of airborne sound. Manikin measurements do not take into account the range of real-ear bone conduction pathways that reduce noise attenuation. However, they allow accurate evaluation of the relative attenuation characteristics available from a particular earphone design over the entire 40Hz to 10 kHz measurement range afforded by the ear simulator.

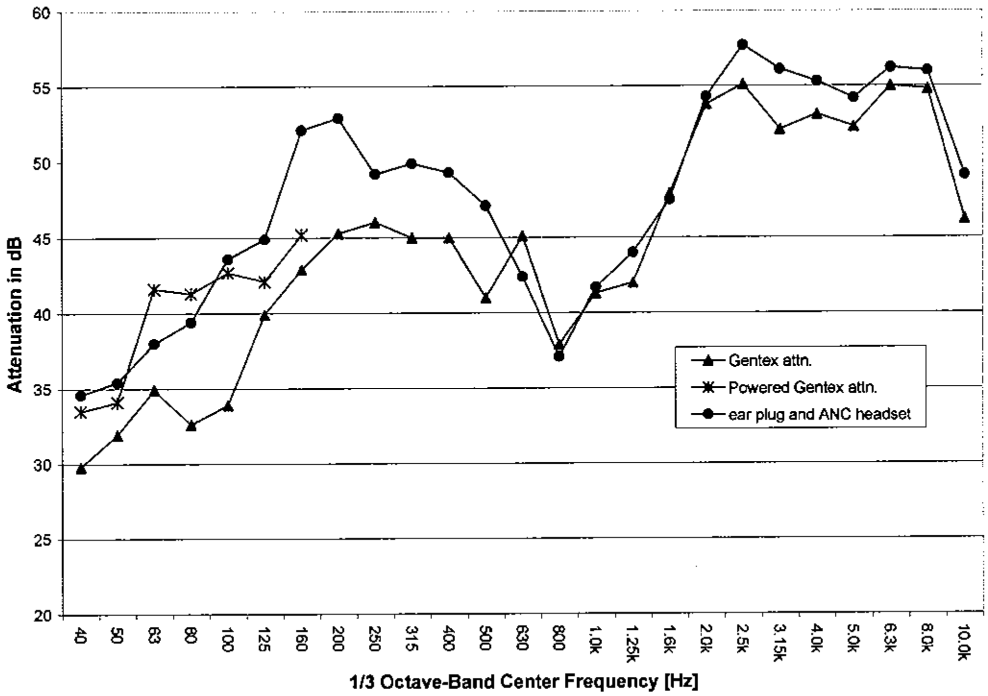

Figure 8. Noise attenuation characteristics of Gentex noise reduction earphone prototype.

NOISE ATTENUATION RESULTS

Figure 8 plots the noise reduction characteristics of the Gentex prototype. ANC headphone/earplug baseline data are included as a reference. As seen in the figure, just the passive attenuation available from the Gentex noise reducing insert earphone is more than adequate for our application. Above the 40 Hz band, results show a 32 dB or greater reduction in noise up to the 10k Hz band. Only partial data on Gentex ANC performance is shown. The active noise reduction in the prototype had artifact clicks, which interfered with spectral analysis above the 160 Hz band. Results in the region from 200 Hz to 10k Hz were confounded with the energy generated by those faint clicks. As a consequence these data are not presented.

INFORMAL LISTENING EVALUATION

A unique and highly desirable feature of the earplug is the ability to extract the voice communications of the wearer using an internal microphone designed to extract signals within the noise-protected ear canal. An informal subjective evaluation of the ability of the prototype earplug device to provide voice communication from the protected wearer as he spoke in over 100dB SPL noise field was done using the available Phase I prototypes. In this evaluation, the digitally processed output of the internal microphone was fed to a remotely located headphone amplifier and distributed to several pairs of high fidelity consumer headphones in a listening room. Several NSMRL staff members, all expert listeners, were pleased with the proof of concept prototype. The device uses several methods of signal processing to maintain noise reduction in the ear, applying ANC only under the most intense noise conditions. With outside noise levels in excess of 100dB SPL, ANC was not required, yet subjectively the fidelity of the digitally processed speech was at least as good as normal clear telephone communications in moderate room noise. Voice was extremely clear with little noise intrusion. In comparison, most communications systems would be unintelligible in this intense noise test situation. For demonstration purposes the ANC was activated to further reduce outside interference into the ear canal. External background noise was reduced even further, though the talker's voice became restricted to a more telecommunications-like bandwidth. That slight reduction in signal quality emphasized the fact that the DNR signal quality without ANC was well beyond normal telecommunications fidelity despite an external ambient noise level in excess of 100 dB SPL.

SUMMARY

Newer extended bandwidth afforded by modern A/D converters has enhanced the utility of broadband search and aural tracking operations. While earphones with appropriate bandwidth are essential they are of limited use unless they can effectively present the entire signal to the listener. Given the spectral content of airborne noise levels measured on current sonar suites, only ANC earphones can, at the present time, effectively attenuate lower frequencies. The presence of such low-frequency energy interferes with critical listening rendering the best closed-headshell professional studio monitor headsets useless. None of the current or previously manufactured passive attenuation models were effective in reducing the intrusion of low frequency noise into the headshell. The current Submarine Virginia Series X ANC headset, due to its noise attenuation and extended frequency response bandwidth, meets the needs of critical listening in spaces containing low frequency equipment noise. A more desirable solution can be found in the use of miniature digital noise reduction insert earphones. The current research provides assessment of a prototype DNR insert earphone device that with minor modifications can meet that requirement. Frequency response needs to be upgraded as was done on the Bose ANC headset. Given the capabilities of digital processing, this is a minor issue. Given the concentration of operators and console hardware anticipated on future systems, these earphones can also serve to selectively reduce speech interference from adjacent operators. With the proper response modifications, these specialized earphones are also essential for Advanced Rapid COTS Insertion (ARCI) systems. Application of these earphones for surface naval operations is also strongly recommended.

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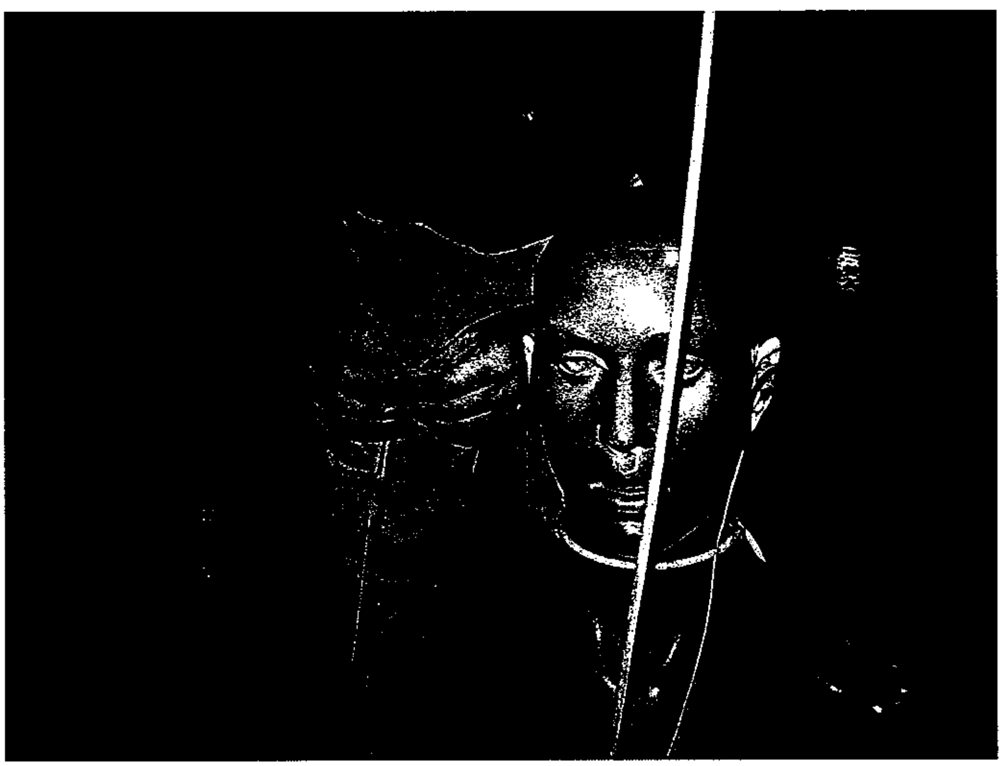
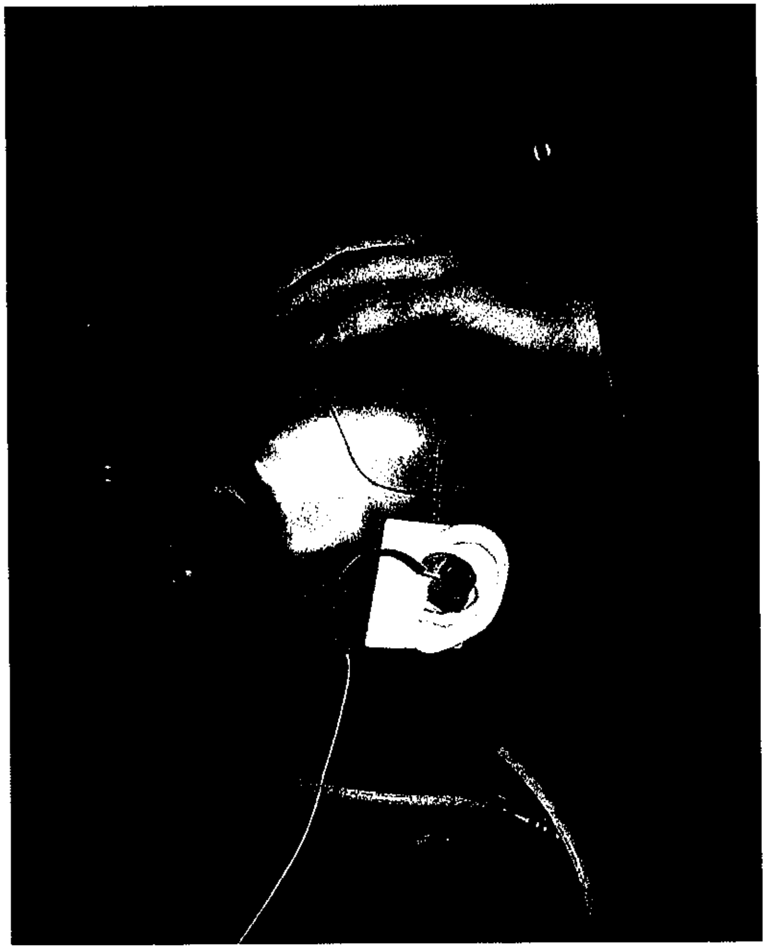
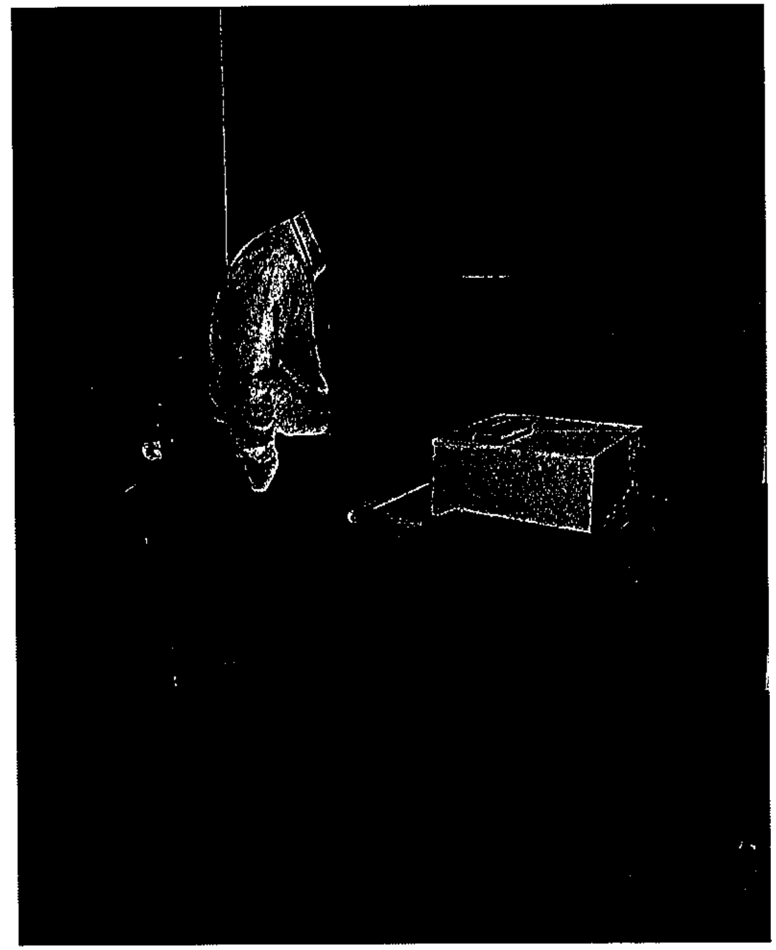
APPENDIX

Gentex Insert-Earphone Noise Attenuation Testing Pictorial







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14. ABSTRACT

Evaluation of Commercial Off-the-Shelf (COTS) headset products confirmed our decision to press for development of high fidelity sensor operator earphones capable of removing low-frequency noise through active signal processing. The current research assesses a prototype Digital Noise Reduction (DNR) insert earphone device, with in-ear 2-way communications that, with minor modifications, can meet those requirements. Noise attenuation measurements show the prototype capable of greater than 32 dB reduction in airborne sound in the 1/3-octave bands from 50 Hz to 10kHz. This was achieved through microprocessor-controlled digital noise reduction, without needing further application of onboard active noise cancellation (ANC) processes. Frequency response, while adequate for speech, needs to be upgraded for use by sonar operators as was done on several ANC headsets. Given the capabilities of digital processing, this is a minor, though critical, issue.

15. SUBJECT TERMS

Sonar Operator; Earphones; Digital Noise Reduction; Active Noise Cancellation; Low Frequency Noise

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